

PHYSICS 665. Contemporary Quantum Theory: Topology in One-Particle and Many-Body Systems

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Course Credit: 3 semester hours.

Lectures: Tu-Th, 1:00-2:15pm.

Format: A lecture course with some topics left for self-study, on which the students will be expected to give in-class presentations. The course may have a final exam (to be confirmed).

Course Description

This course will introduce some of the contemporary techniques used in quantum field theory, with applications in condensed matter theory and high-energy physics. The course will not duplicate the existing courses in the Physics Department on quantum field theory, but rather extend beyond the topics usually covered in those courses, *focusing in particular on the topological aspects*.

This class will attempt to cover a very broad subject, namely that of the role played by geometry and topology in quantum physics. To that end, I'll introduce the basic concepts of differential geometry, which has many applications from the theory of general relativity to the shape of soap bubbles. Many quantum effects (for instance, gauge theories, Aharonov–Bohm effect, Berry phases, Yang–Mills fields, *etc.*) have a natural description in the language of differential geometry, using the mathematical concepts of connections and fibre bundles. The course will introduce some key notions from topology, such as homotopy and homology, and discuss their applications in physics, from the theory of vortices in superconductors, to monopoles in non-Abelian gauge theories, to instantons in Yang–Mills theory.

Prerequisites: Solid knowledge of quantum mechanics (equivalent to graduate PHYS 521) is required. It *is* possible to take the present course without prior exposure to quantum field theory (QFT), however acquaintance with the latter is desirable, for instance in the form of either PHYS 622 (“QFT”) or PHYS 664 (“Many-body formalism”), or equivalent courses at other institutions.

Knowledge of differential geometry (for instance MATH 401) will be advantageous but is not required. Similarly, familiarity with point-set topology and its basic concepts (for instance MATH 443) would be useful but is not essential.

Objectives: This course is geared primarily towards aspiring theoretical physicists, with the goal to expose them to some of the modern mathematical and field-theoretical tools in quantum physics. This said, the first part of the course may be suitable to any graduate student, not necessarily a theorist, interested to learn about the topological phases of matter, which have garnered special attention of the condensed matter physicists in the past 15 years.

Learning outcomes: To grasp basic ideas behind the topological quantum phases of matter and defects therein. To gain familiarity with the mathematical concepts in differential geometry and topology, and their role in modern quantum physics.

Recommended Texts:

1. T. Frankel, *The Geometry of Physics: An Introduction* (Cambridge Univ. Press, 1997);
2. K. Jänich, *Topology* (Undergraduate Texts in Mathematics, Springer, 1994).
3. A. Altland and B. Simons, *Condensed Matter Field Theory*, esp. Ch. 9 (Cambridge Univ. Press, 2010).